Climate Variation and Incidence of Ross River Virus in Cairns, Australia: A Time-Series Analysis

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In this study we assessed the impact of climate variability on the Ross River virus (RRv) transmission and validated an epidemic-forecasting model in Cairns, Australia. Data on the RRv cases recorded between 1985 and 1996 were obtained from the Queensland Department of Health. Climate and population data were supplied by the Australian Bureau of Meteorology and the Australian Bureau of Statistics, respectively. The cross-correlation function (CCF) showed that maximum temperature in the current month and rainfall and relative humidity at a lag of 2 months were positively and significantly associated with the monthly incidence of RRv, whereas relative humidity at a lag of 5 months was inversely associated with the RRv transmission. We developed autoregressive integrated moving average (ARIMA) models on the data collected between 1985 to 1994, and then validated the models using the data collected between 1995 and 1996. The results show that the relative humidity at a lag of 5 months ($p < 0.001$) and the rainfall at a lag of 2 months ($p < 0.05$) appeared to play significant roles in the transmission of RRv disease in Cairns. Furthermore, the regressive forecast curves were consistent with the pattern of actual values. ***Key words*: autoregressive integrated moving average, climate change, cross-correlation function, disease prediction, Ross River virus.** ***Environ Health Perspect*** **109:1271–1273 (2001). [Online 28 November 2001]**

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Ross River virus (RRv) is the most common and widespread arbovirus infection in Australia (*1,2*). It was first identified as epidemic polyarthritis in the Murrumbidgee River area of New South Wales, Australia, in 1928 (*3*). The causative agent was recognized as a mosquito-borne arbovirus in 1960 (*4*). A virus was isolated from a pool of *Aedes vigilax* mosquitoes collected around Ross River near Townsville in 1963 after which the virus was named (*5*).

RRv is characterized by arthritis, rash, and constitutional symptoms such as fever, fatigue, and myalgia (*2,6*). In most years, RRv is recorded as geographically scattered cases throughout the year, but with the preponderance of cases occurring from January to May, particularly in the tropics (*7*).

For the years 1991–2000, 53,347 laboratory-confirmed cases of RRv infection were reported (*8*). Numerous studies have examined the relationship between climate variation and arboviral disease (*9–12*). Several models have been developed to assess the potential impact of such future climatic changes on health (*10*). The incidence of RRv has been linked to climatic factors, particularly rainfall, high tide, and temperature (*11,12*). However, the quantitative relationship between climate variation and the transmission of arboviruses remains to be determined.

Time-series methodology has a long history of application in econometrics, particularly in forecasting. Recently it has been used extensively to study the effects of environmental exposures (e.g., air pollution on mortality and morbidity) (*13–17*).

Autoregression integrated moving average (ARIMA) models are a useful tool for analyzing nonstationary time-series data containing ordinary or seasonal trends (*17,18*). Because most of climate-sensitive diseases have seasonal patterns, ARIMA models may be suitable for this type of data.

In this study we aimed to examine the potential impact of climate variability on the transmission of RRv infection using the ARIMA transfer function and to assess the potential predictors of the RRv incidence.

Materials and Methods

Cairns is the main coastal city of north Queensland in Australia (Figure 1). Its population was 49,332 on 31 December 1999. It is about 1,600 km from Brisbane, capital of Queensland (*19*). Cairns is also a major tourist city, and the transmission of RRv has a considerable impact on tourism there.

We obtained the computerized data set on the notified RRv cases in Cairns for the period 1985–1996 from the Queensland Department of Health. The data on RRv were routinely collected for the National Notifiable Disease Surveillance system, which is conducted under the auspices of the Communicable Diseases Network Australia-New Zealand. Climate and population data were obtained from the Australia Bureau of Meteorology and the Australia Bureau of Statistics, respectively. Climate data consisted of monthly maximum and minimum temperature, monthly rainfall, monthly relative humidity at 0900 and 1300 hr, and monthly high tidal levels. We considered high tidal level a climate variable in this study because of its relevance to climate change.

To establish whether a relationship exists between two variables observed over time, the obvious approach is to compute correlation coefficients between the two series over a range of time lags (*20*). Here, we fitted ARIMA models with the time series of the incidence of RRv (*21*). We checked the goodness-of-fit of the models for adequacy using both time-series (residual autocorrelation functions) and classic tools (check of the normality of residuals). We divided the data file into two data sets: a model-building (Janurary 1985–December 1994) and a validation (January 1995–December 1996) set. We used the former to construct the ARIMA model and the latter to validate the model.

Results

Table 1 shows the cross-correlation coefficients between climatic variables and the incidence of RRv. The maximum temperature in the current month and rainfall and relative humidity at 1500 hr at a lag of 2 months were significantly associated with the incidence of RRv. However, the relative humidity at a lag of 5 months was inversely associated with the RRv incidence.

The ARIMA models (Table 2) show that the relative humidity at a lag of 5 months ($p < 0.001$) and rainfall at a lag of 2 months ($p < 0.05$) were statistically significantly related to the transmission of RRv disease in Cairns. However, for maximum and minimum temperature and tidal level, no statistically significant association with the RRv incidence was observed.

Figure 2 shows that there was no significant autocorrelation between residuals at different lag times. The graphic analysis of residuals shows that the residuals in the model appeared to fluctuate randomly around zero, with no obvious trend in variation, as the predicted incidence values increase (Figure 3). Thus, no violation of assumptions was indicated.

The regressive forecast chart indicates that the predicted value and the actual incidence of RRv matched reasonably well.

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The model was based on the data collected during the period 1985–1994. The incidence of RRv from January 1995 to December 1996 was theoretically predicted by the model and validated by the actual values (Figure 4).

Discussion

The results of this study indicate that climate variability is clearly associated with the incidence of RRv disease. In particular, relative humidity and rainfall seem to have played a significant role in the transmission of RRv in Cairns.

Humidity is an important environmental parameter with respect to the survival of mosquitoes. Relative humidity is defined as the ratio of water-vapor content of the air to its total capacity at a given temperature (*22*).

Figure 1. Map of Cairns, Queensland, Australia.

Relative humidity affects dispersal, mating, feeding behavior, and oviposition of vector species. Under conditions of optimal humidity, mosquitoes tend to survive for a longer period, which allows them to disperse farther and to have a greater opportunity to participate in transmission cycles (*23,24*). Humidity also affects the rate of evaporation of water at breeding sites. In this study, the regression coefficient of relative humidity at a lag of 5 months was inversely and significantly associated with the RRv incidence in the ARIMA model. This relationship might occur because the decrease in relative humidity can reduce the flow of water in streams and thus produce stagnant pools, often high in organic matter, which make perfect breeding sites for a number of mosquito species. Added to this, such reduced water sources are likely to become central to water requirements of birds and other animals, thus increasing the potential for vertebrate host–insect transmission cycles (*23*).

Rainfall or precipitation is one of the important elements for the breeding and development of mosquitoes (*25,26*). All mosquitoes have aquatic larval and pupal stages and therefore require water for breeding (*10,23*). Considerable evidence has accrued to show that heavy rainfall and flooding can increase mosquito breeding and therefore the number of outbreaks of arboviral disease in Australia (*23,24*). Examples are readily available of RRv outbreaks in various parts of Australia (*11,23*). In general, epidemic activity of arbovirus is observed more often in temperate areas with heavy rainfall and flooding, whereas in tropical Australia transmission occurs throughout the year (*27*). Nevertheless, distinct epidemics do occur in northern Australia, and are especially associated with heavy monsoonal rainfalls. Over the past decade, major outbreaks caused by heavy rainfall have been reported from several states in Australia (*11,27*). Timing of rainfall is as important as the amount of rain. For example, major outbreaks of RRv disease in southwestern Australia usually follow heavy late spring or summer rains, but not heavy winter rains (*23*). In contrast, outbreaks in the arid Pilbara region of western Australia usually follow heavy autumn and winter rains, not summer rains (*23*). These observations may be explained by interactive effects of temperature and rainfall on the viruses and their vectors. More frequent rains may replenish existing breeding sites and maintain higher

Table 2. ARIMA regression analysis of the incidence of RRv on climatic variables in Cairns.

Variable	β	SE	*p*-Value
Rainfall	0.001	0.001	0.032
Relative humidity	–0.061	0.017	0.001
Constant	6.184	1.325	0.000

Table 1. Cross-correlation coefficients between climate variables and incidence of RRv in Cairns, Queensland.

Variable	Lag0	Lag1	Lag2	Lag3	Lag4	Lag5	Lag6	Lag7
MaxT	0.214*	0.169	–0.002	0.140	0.183	0.065	–0.025	0.125
MinT	–0.080	0.042	0.007	–0.030	0.056	0.128	0.004	–0.068
Rainfall	0.101	–0.019	0.223*	0.181	–0.122	–0.165	0.013	0.002
RH, 0900 hr	–0.064	0.053	0.195	0.067	–0.177	–0.293*	–0.051	0.068
RH, 0300 hr	–0.146	0.117	0.206*	0.079	–0.074	–0.224*	–0.060	–0.031
HT	0.191	0.064	0.177	0.123	–0.165	–0.018	–0.104	0.069

Abbreviations: HT, high tide; LagX, lagged months; MaxT, maximum temperature; MinT, minimum temperature; RH, relative humidity.
*$p < 0.05$.

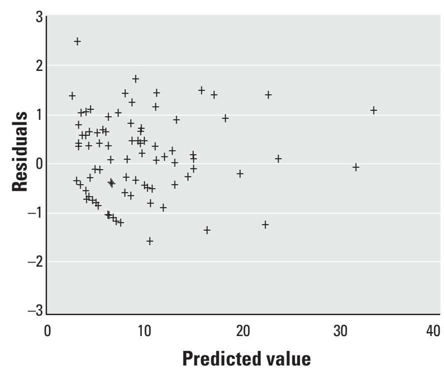

Figure 3. Scatterplot of residuals.

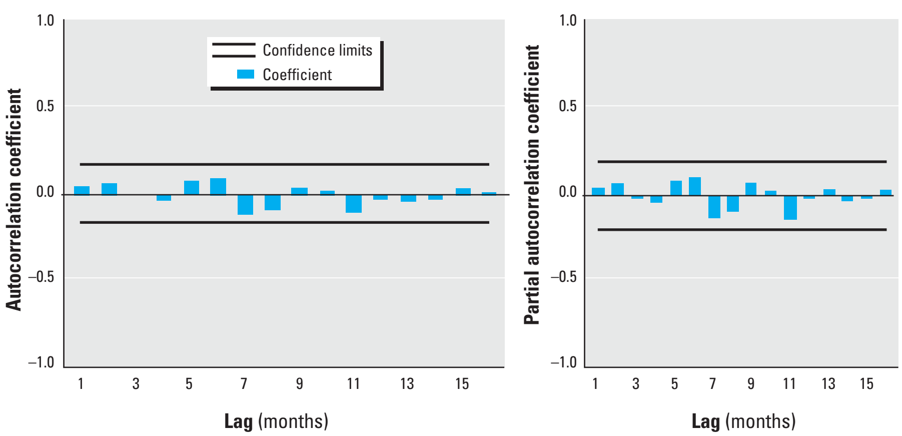

Figure 2. Autocorrelation and partial autocorrelation of residuals.

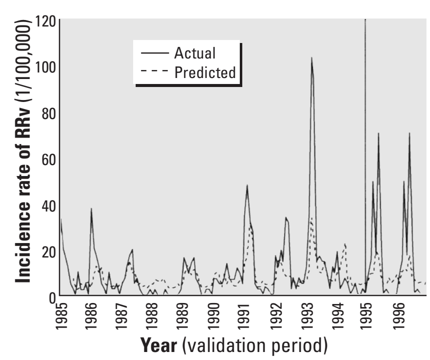

Figure 4. Regressive forecasts of RRv in Cairns, January 1985–December 1996.

levels of humidity, which assists in dispersal and survival of adult mosquitoes (*10,23*). The results of this study corroborate the previous finding that rainfall is an important factor in transmission of RRv in Australia.

Temperature has significant impacts on the length (*28–30*) and efficiency (*31–33*) of extrinsic incubation of arboviruses in their vectors (*34*) and on the survival of adult mosquitoes (*30*). Thus, most studies have shown that mosquitoes exposed to higher temperatures after ingestion of virus become infectious more rapidly than mosquitoes of the same species exposed to lower temperatures. Maximum temperature affects the breeding and survival of adult mosquitoes; for example, some species of mosquito are temperature-limited in their breeding (*2,34–36*). However, temperature is not a significant determinant in the RRv transmission in Cairns, perhaps because Cairns is located in the tropical zone and the temperature is usually high.

Forecasting arboviral diseases using routinely collected data is still in its infancy, but as more data become available, forecasting offers the potential for improved contingency planning of public health interventions and more broadly based forecasting. The role of environmental conditions, particularly of rainfall on vector breeding and vector abundance and of humidity on vector survival, are all well established, but it is evident that many other factors (e.g., virus strain, mosquito population densities and survival, human behavior, population immunity, and housing characteristics) must be incorporated in the modeling process.

In this study, the model well reflected the trend of the incidence of RRv in Cairns. Of course, it is not yet possible to predict with precision the extent and magnitude of the alteration in the disease pattern as global warming continues. Computer models must be developed on the basis of in-depth research to predict possible epidemic activity under different environmental conditions and as a means of predicting future consequences of environmental change.

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